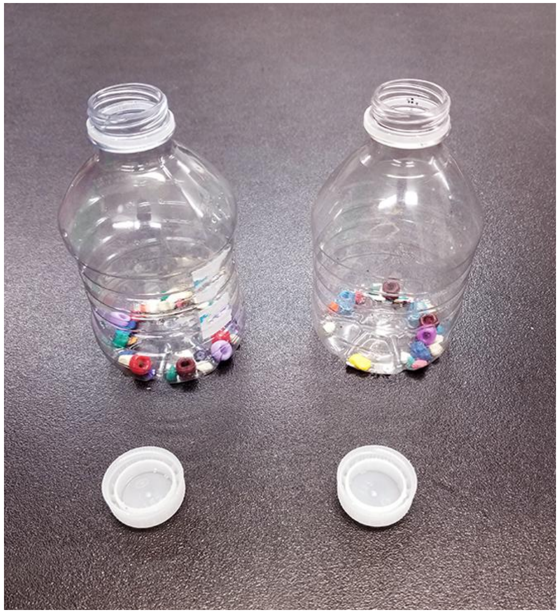
Gravitational Lensing

Thought Experiment

- Take two identical clear bottles
- Place a handful of colorful beads at the bottom of each
- Fill one jar with water all the way to the top, sealed with no air bubbles
- Seal the other jar with no water inside, just air




Thought Experiment

How do you know for certain that water is present in one of the bottles even though they look the same?

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How do you know for certain that water is present in one of the bottles even though they look the same?

- One container will be heavier **(non-visible mass)**
- If you flip the bottles, the beads will move differently through one compared to the other **(kinematics)**
- The beads inside the bottle with water look distorted **(visual indicators)**

Thought Experiment

We can’t directly see the water in the bottle, but we know it’s there based on how it interacts with things around it.

Can you think of anything else on Earth that acts like this?

What measurements need to be taken in order to detect this thing? That is, how do you measure it indirectly?

Dark Matter

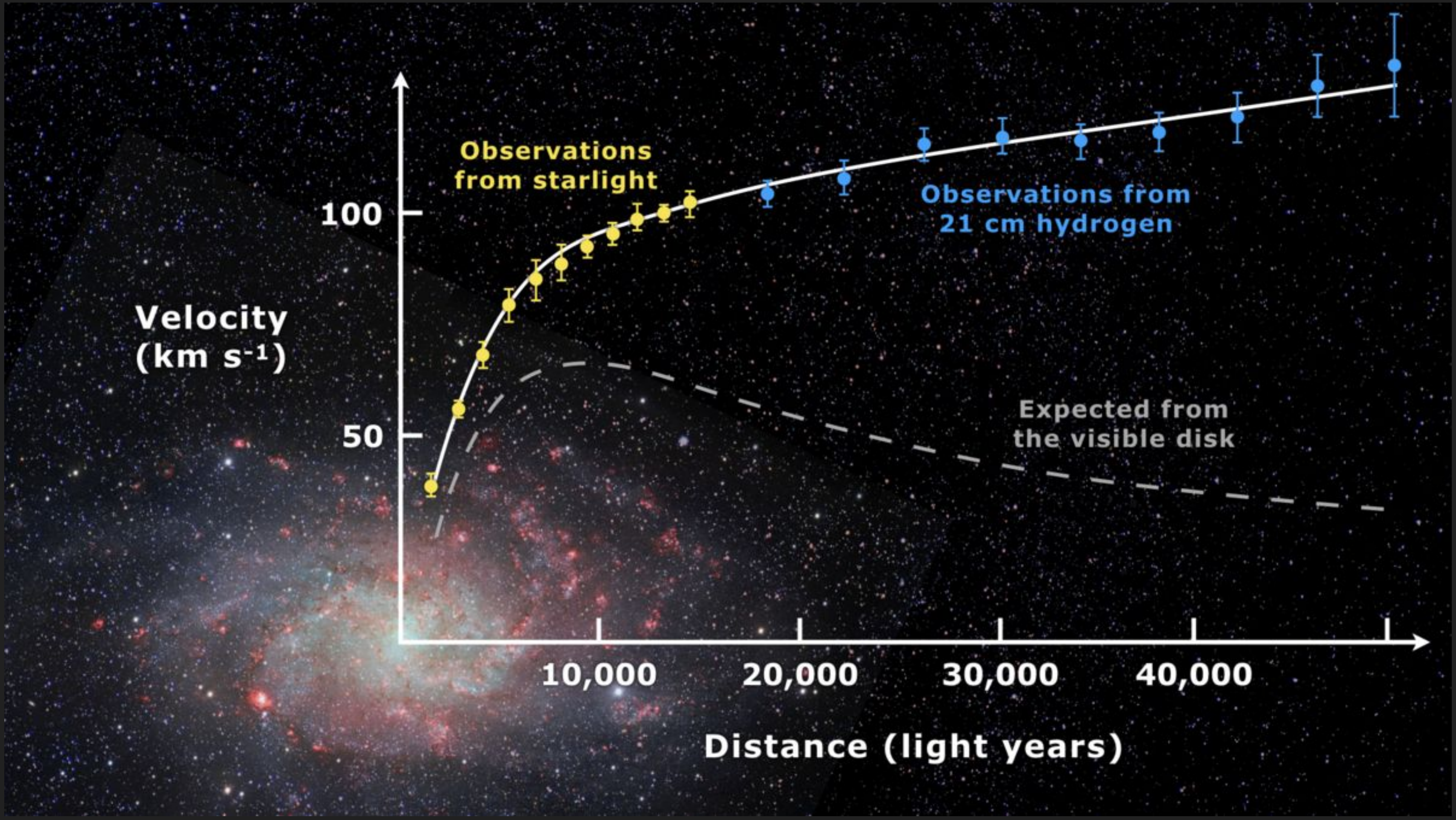
Similar to the water in the previous thought experiment, we can’t actually see dark matter in space.

So how do we know for certain that dark matter is present in space if we can’t see it?

- Distorted images of distant galaxies **(visual indicators)**
- Effects on the ways that galaxies and stars move and interact **(kinematics)**
- Extra mass in the universe **(non-visible mass)**

We see the effects of this **‘missing mass’** everywhere!

Vera Rubin was the first to see that stars in galaxies are moving faster than they ought to according to how much visible mass is present - there must be dark matter!



Dark Matter

In general, dark matter:

- **doesn't emit or reflect sufficient light** for us to be able to detect it
- exerts a gravitational force both on light and on the sources of light (e.g. stars and galaxies) that we observe in space

We actually know more about what dark matter *isn't* than what it *is*. A few guesses:

- Brown dwarfs, "failed stars" that never ignited because they lacked the mass needed to start burning
- Neutron stars or black holes, very dim and very dense!
- Neutrinos, fast moving, hard to detect particles

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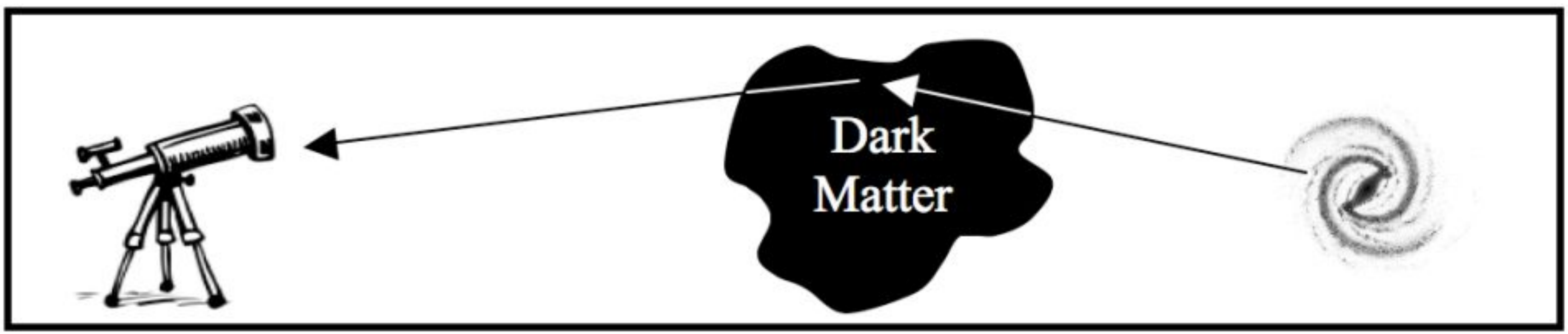
Dark Matter

However, there are problems with each of these suggestions. So far, there don’t seem to be enough brown dwarfs for all of the dark matter that’s expected to exist in the universe. Black holes and neutron stars are also rare.

In fact, dark matter may not be made up of the matter we are familiar with. It could be **weakly-interacting particles** that have been predicted by theory but that scientists haven’t yet observed - we’re pretty sure this is the case!

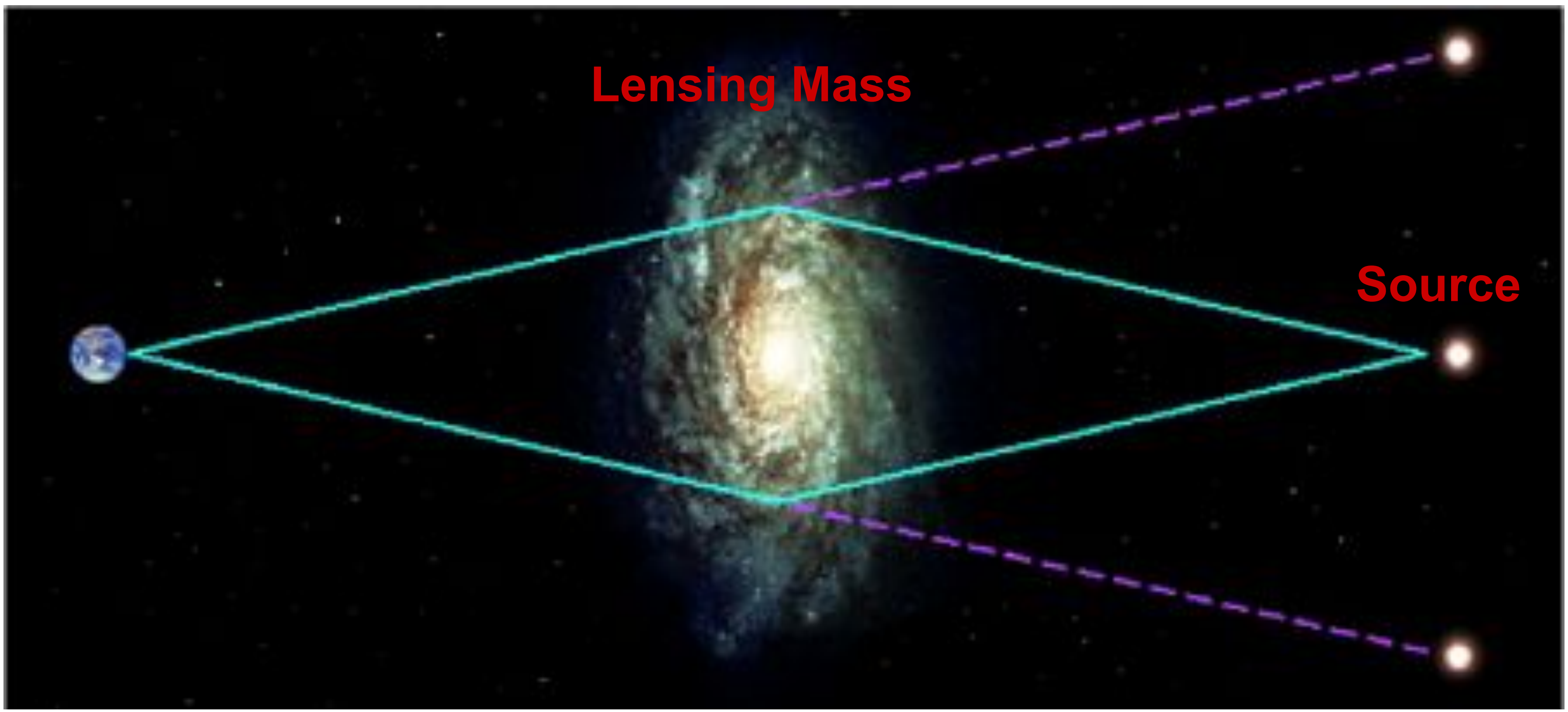
Gravitational Lensing

Putting aside the fact that we don't know exactly what dark matter is made of, we know a lot about how to measure it, one way being via gravitational lensing - described by general relativity.



Gravitational Lensing Example

Apparent Source Position



Apparent Source Position

Gravitational Lensing

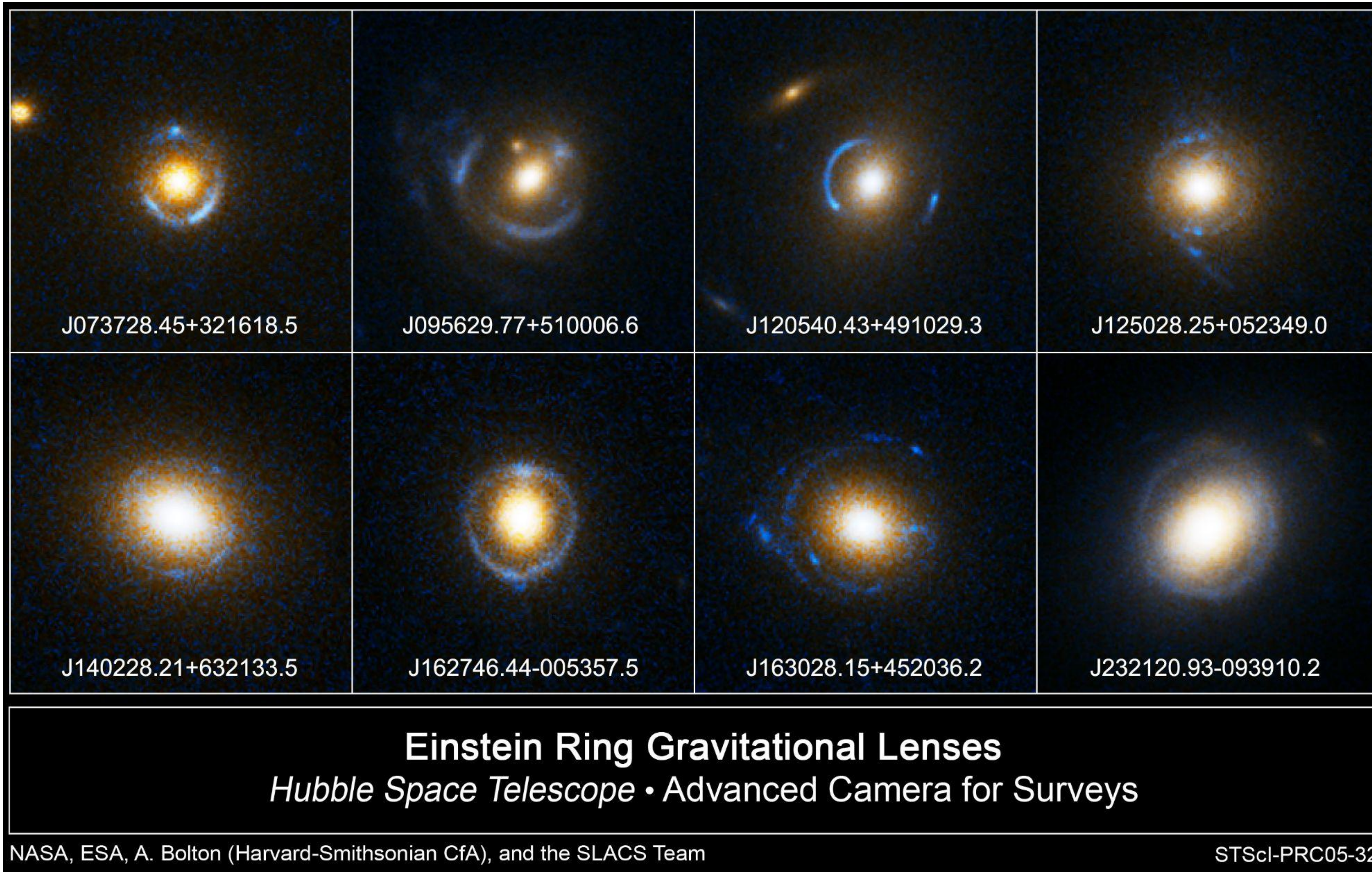
Can be separated into two categories:

- **Weak lensing** occurs when shapes are slightly stretched out and distorted, hard to see with the human eye and often requiring statistical analysis by computer programs
  - **Caused by large scale structure** in the universe

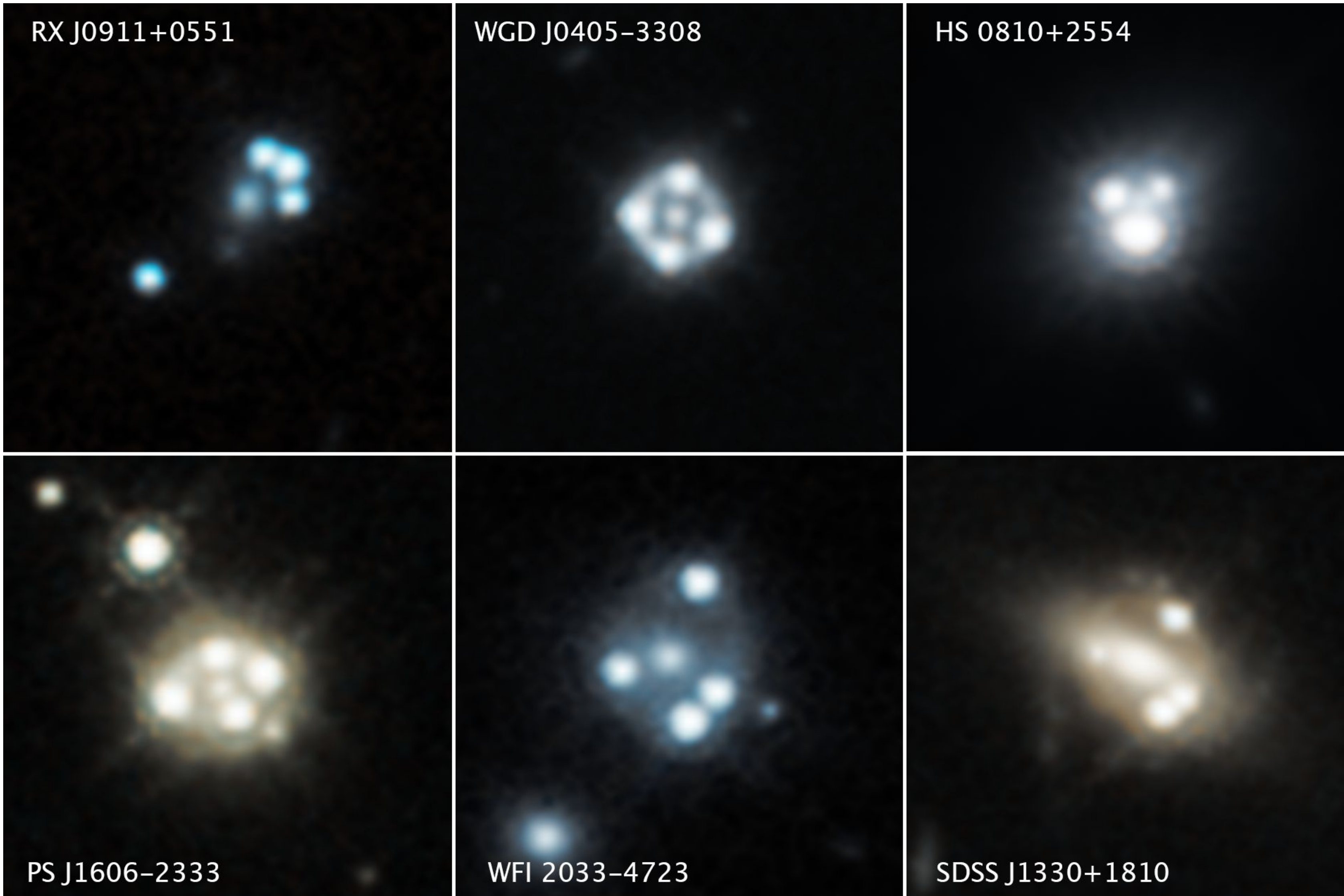
- **Strong lensing** is visible with the human eye and generally consists of stretched arcs or multiple images
  - **Caused by very massive objects**, like galaxy clusters

We’ll be focusing on strong lensing since it’s easier to detect.

“Einstein Rings”

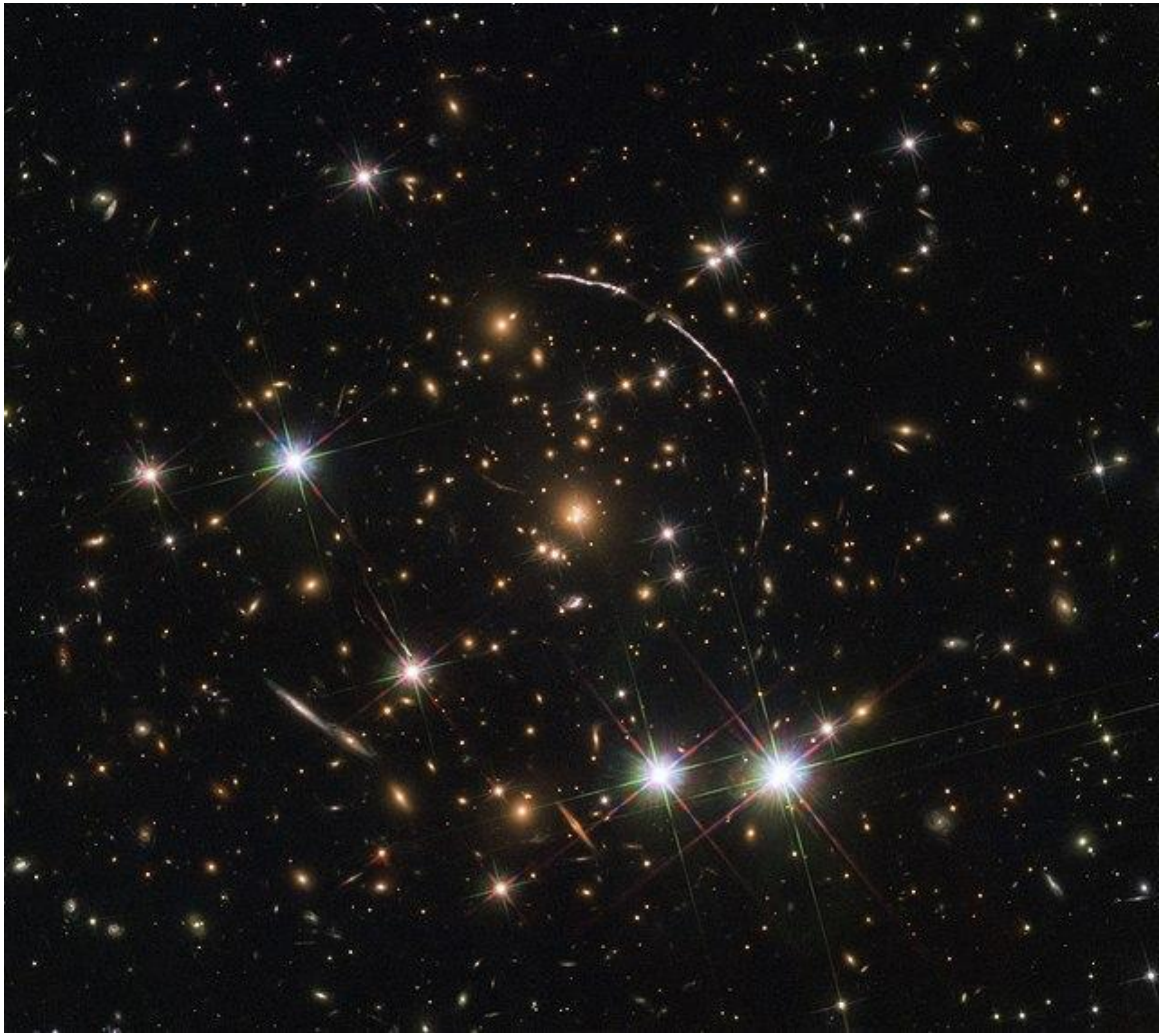


“Einstein Crosses”



Gravitational Lensing

Einstein rings and Einstein crosses are the most obvious features of strong lensing, but arcs and streaks are also signatures of the strong lensing effect.



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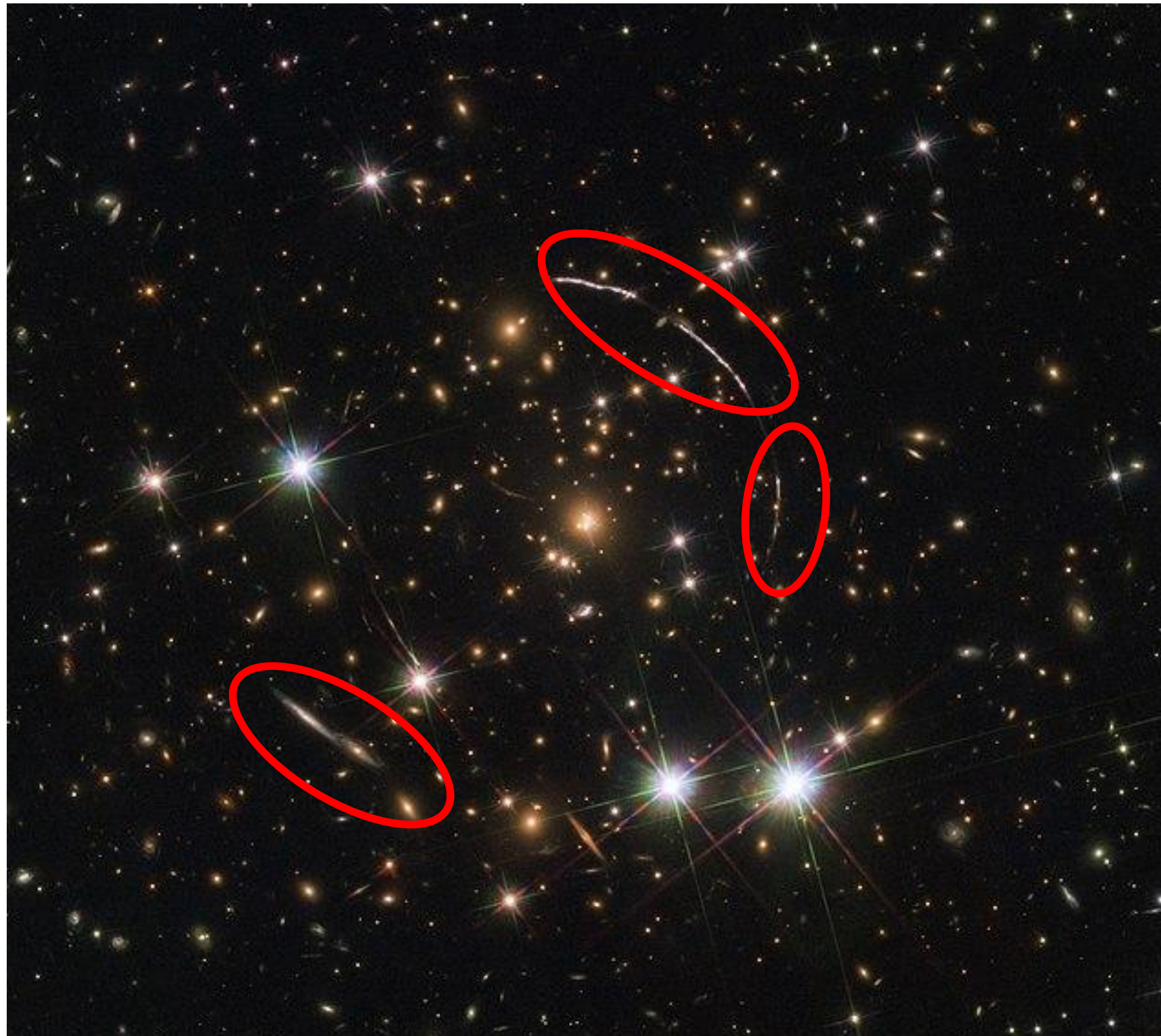
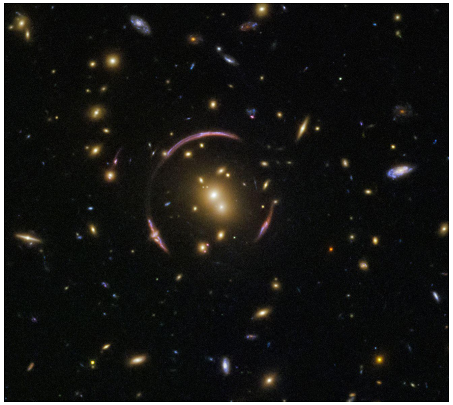
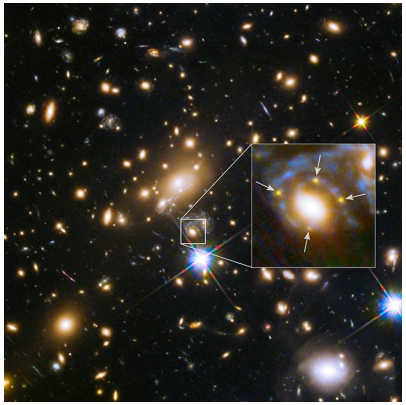
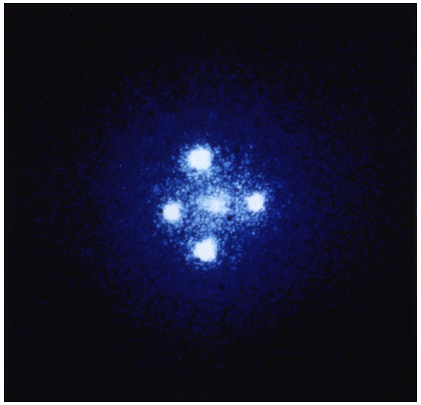


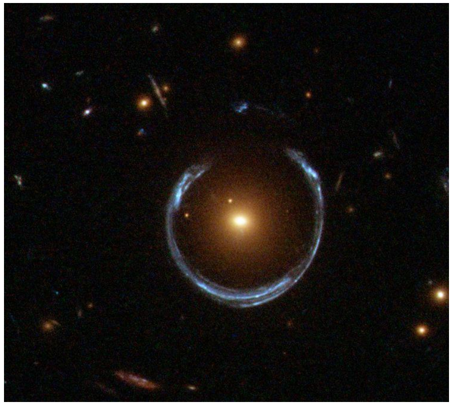
Gravitational Lensing

Maybe do a quick matching game in nearpod with some different photos and identifying the gravitational lensing features (could be matching or quiz-style). Or just show a slide or three with pretty pictures.









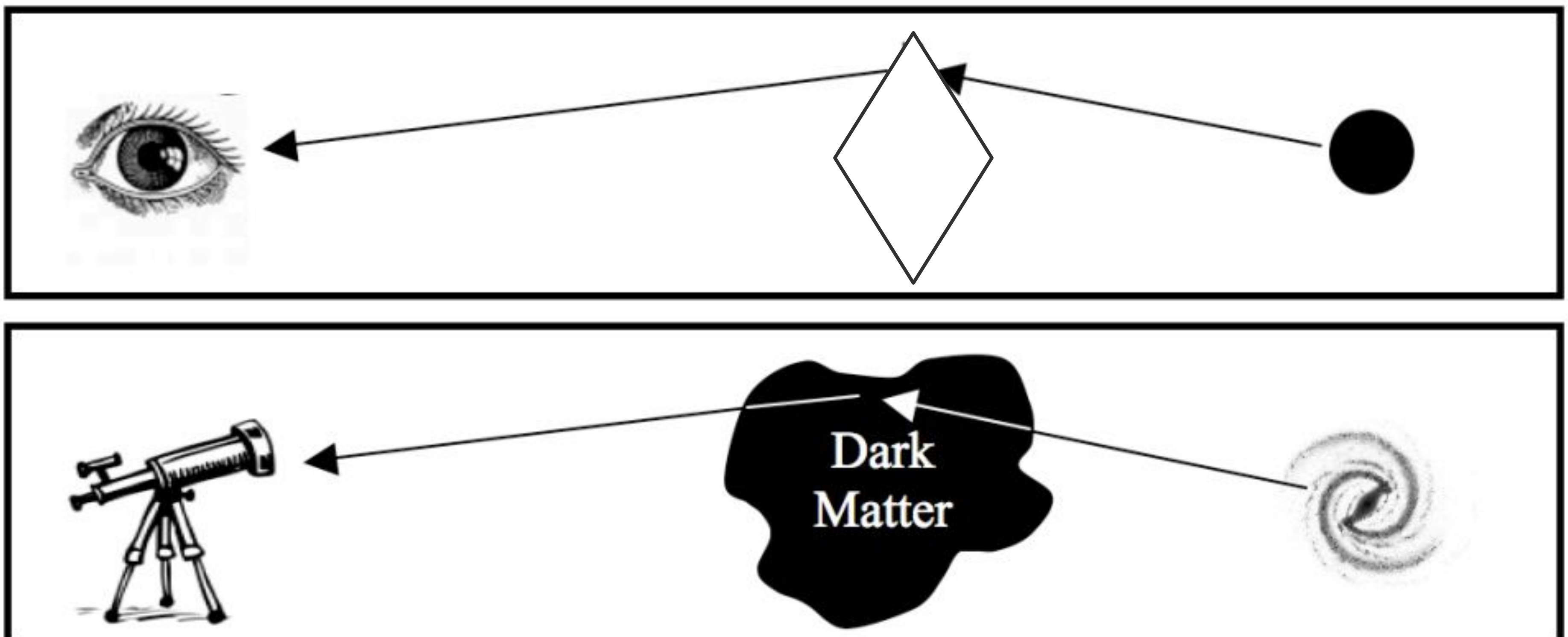
Group Activity

Notes:

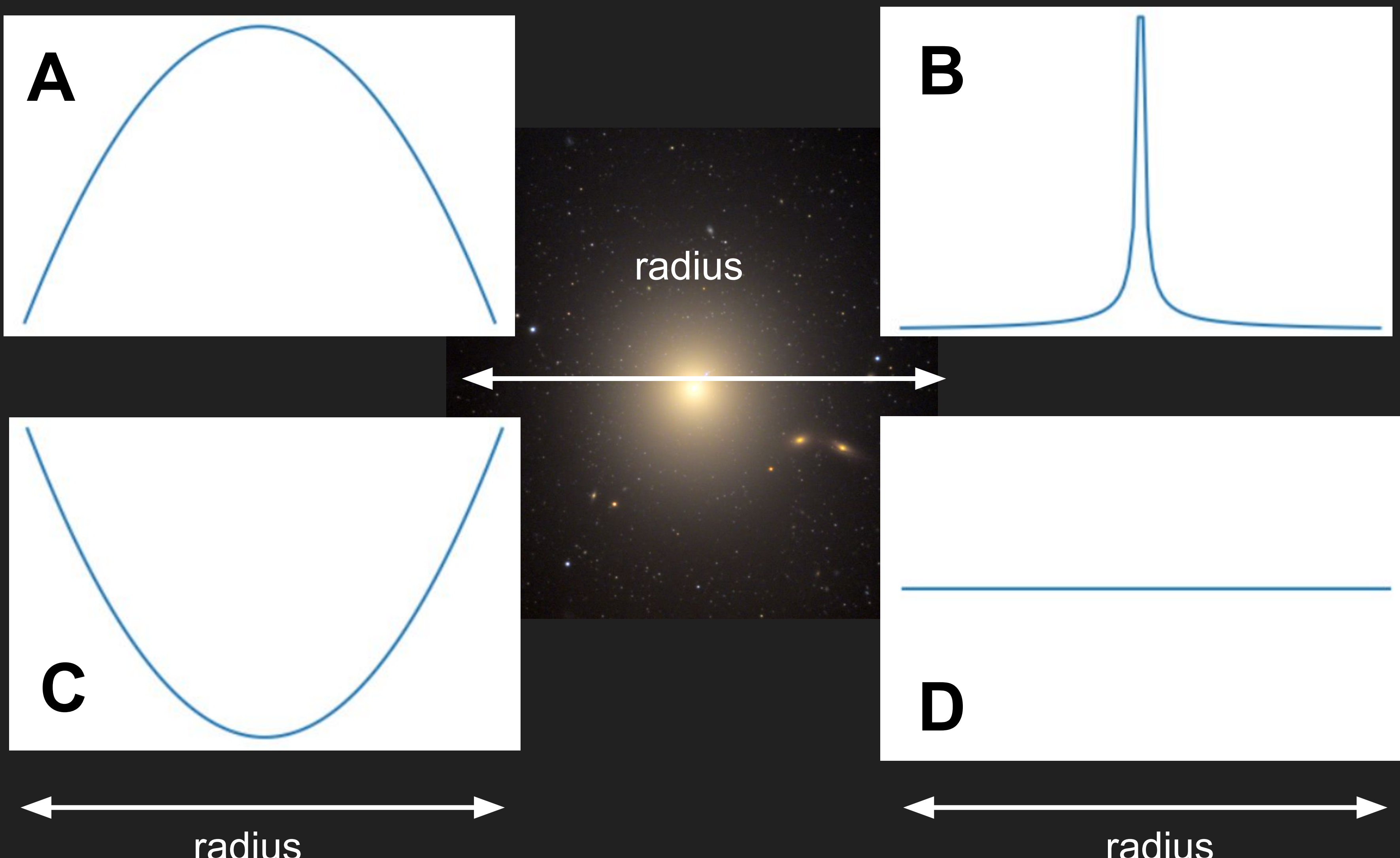
- Figure out which glass lens option is a good representation of a gravitational lens?
- add hubble deep field to lesson (we thought this was empty space and look at it!)
- probably some extra content after this full group part before we break out into the smaller lab groups.

Gravitational Lensing

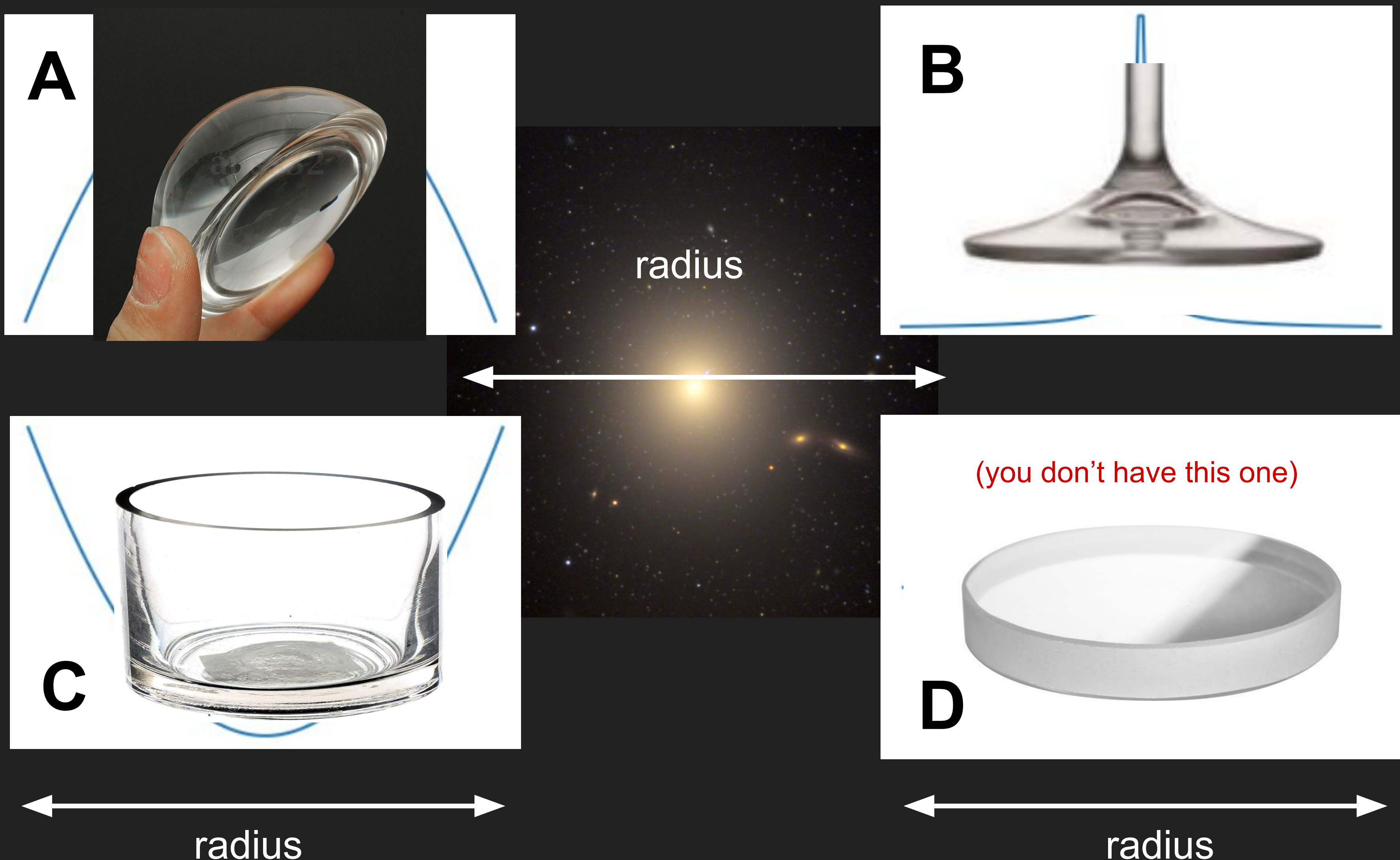
The distortion can be approximated by a glass optical lens, if you make a lens of the right shape. In fact, the **thickness** of the glass can act a lot like the proportional **amount of dark matter**!



How do you think ***Mass*** is distributed in this galaxy?



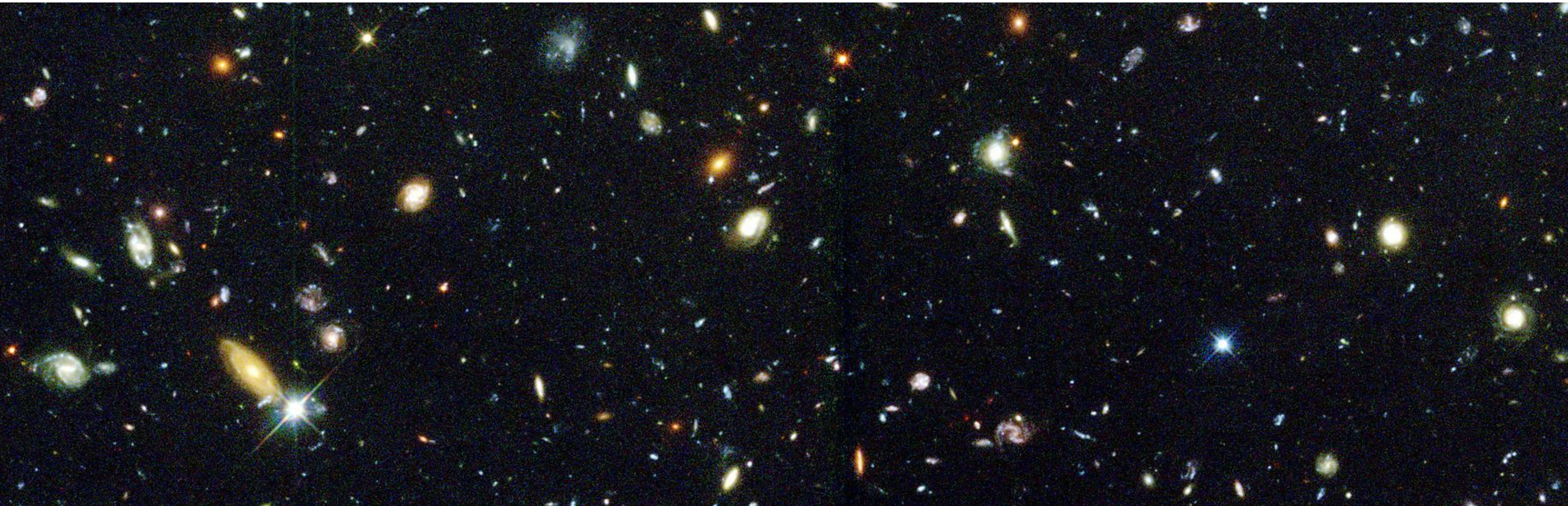
Which **lens shape** is the most like the matter in a galaxy? Test the lenses you've received by starting through Section 1!



Using the Hubble Deep Field as unlensed sources

A while back, scientists pointed one of the best telescopes we had at ‘empty space’ and exposed for a very long time.

They found that ‘empty space’ was full of many rich galaxy types! Our universe suddenly looked much much bigger. We’ll be using some of these as your background sources to lens with your glasses.



Group Activity: Section 2

We can use the bottom of a wine glass as our “lens” or “mass” to do some experiments at home.

Gather the following materials:

- Graph paper
- Lab worksheet
- Black marker
- Stemmed glassware (2)
- ~~Candle holder~~
- ~~Magnifying dome~~

Questions before we start?

Questions after we end? Go to our evening office hours!

Break into groups to get a feel for gravitational lensing!

You'll be working through the lab with your group. If anything isn't clear ask your assigned volunteer to help!

Periodic notifications will go out so that everyone stays on track.

Finishing early? Try out the spectroscope and lab worksheet on stellar physics!